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HEC Models for Urban Hydrologic Analysis

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INTRODUCTION

HEC Hydrologic Background

As the Corps' national center for hydrologic engineering and analytical planning methods, the Hydrologic Engineering Center, HEC, addresses the needs of the Corps field offices. HEC has developed and supported a full range of simulation models for understanding how water resources systems function[1]. It is assumed that experienced professionals can deduce the appropriate solution to a problem given the insight provided by selective execution of the simulation models. This deduction process has historically been and will continue to be the dominant methodology for planning and operational decisions in the water resources community.

This paper primarily addresses the urban-hydrology software of HEC. Not included in the paper is information about HEC's river hydraulics, flood damage, flood frequency, reservoir system, and water quality models. In recent years, many improvements have been made to: the steady state water surface profile model; the sediment scour and deposition model; and the unsteady flow model. In the area of flood damage analysis, a flood damage analysis package provides a comprehensive set of tools to evaluate flood damage reduction, and a new program accounts for project benefits during flood event operations. HEC also maintains a set of non-point source, river, and reservoir water quality simulation models.

Urban Hydrology Background

The U.S. Army Corps of Engineers flood control responsibility has applied to many geographic settings. The flood damages to be prevented are primarily in urban areas. HEC developed several computer programs and methods to analyze and compute urban flood damage. The principal program is the Flood Damage Analysis Package[2]. The subject of this paper is not the damage computation, but the hydrologic simulation software (e.g. HEC-1) developed for urban areas. The Corps has made flood damage reduction investigations of just about every type of urban area, from sparsely developed areas to major metropolitan areas. For these studies, traditional hydrologic models have been applied to the urban areas; oftentimes, new runoff parameters were added to the models to simulate the particular watershed characteristics of urban areas. Many of the computer simulation models are simply adapted to the particular infiltration, runoff, and channel characteristics of urban areas.

In the Corps Urban Studies Program of the 1970's, new models were developed to meet the specific needs of those studies. In other studies, e.g. the Expanded Floodplain Information Studies, major changes in use of geographic data were made; this was the start of geographic information system, GIS, usage in hydrologic modeling. In all cases, HEC strives to develop physically-based simulation models which are easily applied in ungaged areas. This is especially true in the urban situation. The following sections of this paper discuss the urban hydrology software development and application activities of the HEC.

HEC-1 FLOOD HYDROGRAPH PACKAGE

Background

The HEC-1 Flood Hydrograph Package[3] computer program was originally developed in 1967 by Leo R. Beard and other members of the HEC staff. The first version of the HEC-1 program package was published in October 1968. It was expanded and revised and published again in 1969 and 1970. To simplify input requirements and to make the program output more meaningful and readable, the 1970 version underwent a major revision in 1973. In the mid 1970's, increasing emphasis was being placed on urban storm-water runoff. A special version of HEC-1 was developed which incorporated the kinematic wave runoff techniques that were being used in several urban runoff models. Special versions of HEC-1 were also developed for other purposes. In 1981, the computational capabilities of the dam-break, project optimization, and kinematic wave special versions were combined into a single package. In late 1984 a microcomputer version (PC version) was developed. A menu capability was added to facilitate user interaction with the model; an interactive input developer, a data editor, and output display features were also added.

Current Version

The latest version, Version 4.0 (September 1990), represents improvements and expansions to the hydrologic simulation capabilities together with interfaces to the HEC Data Storage System, HEC-DSS (see later section of this paper). The DSS connection allows HEC-1 to interact with the input and output of many HEC and other models. (DSS will be an important capability for marrying several models needed for complex urban runoff situations as discussed later.) New hydrologic capabilities in HEC-1 include Green and Ampt infiltration, Muskingum-Cunge flood routing, prespecified reservoir releases, and improved numerical solution of kinematic wave equations. The Muskingum-Cunge routing may also be used for the collector and main channels in a kinematic wave land-surface runoff calculation. This new version also automatically performs numerical analysis stability checks for the kinematic wave and Muskingum-Cunge routings. The numerical stability check was added because many users did not check the validity of the time and distance steps used in the model.

In September 1991, an alternate version of HEC-1 (version 4.0.1E) was released for use on extended memory PC's. A hydrograph-array size of 2,000 time intervals is now available in this version. The increased array size reduces limitations encountered when simulating long storms using short time intervals. For example, simulation of a long (96-hour) storm in an urban area at 15-minute intervals requires 384 ordinates just for the storm; more time intervals would be required to simulate the full runoff hydrograph and route it through the channel system. The large-array version also allows greater flexibility in checking for numerical stability of simulation processes (e.g., kinematic runoff and routing computations). The large-array version uses an extended or virtual memory operating system available on 386 and 486 machines.

Urban Hydrology Features

Watershed Runoff

HEC-1 computes runoff using one of several loss methods (e.g. SCS Curve Number or Green and Ampt) together with a either a unit hydrograph or kinematic wave. Kinematic wave was added specifically to address the issues of urban hydrology. It also provided a better physical basis for application in ungaged areas. Before adding the kinematic wave runoff capability to HEC-1, the overall structure of urban runoff computations was analyzed. Urbanization impacts on both infiltration and runoff characteristics were considered. Also, the procedure for applying the model to large urban areas was reviewed. It was noted that runoff is usually computed from two types of surfaces: pervious and impervious. Within a subbasin (the smallest land surface area for which precipitation-runoff calculations will be made), urban drainage systems were found to have a regular structure of overland flow leading to collector channels of increasing size. For example, runoff from a property goes into a gutter, then into various sizes of storm drains until it reaches the main channel (storm sewer).

These characteristics of urban runoff were taken into account in designing the kinematic wave urban capability in HEC-1[4]. The result is a series of runoff elements, Fig. 1, which are linked together. These elements are linked together into a "typical" collector subsystem within the subbasin, Fig. 2. The rationale is that urban developments often have fairly regular storm drain systems which are tributary to a main channel. As shown in Fig. 2, there are two overland flow elements (pervious, the longer and impervious, shorter) which flow into the first collector channel. These overland flow elements allow specification of different infiltration and runoff characteristics, usually one representing pervious surfaces and the other representing impervious surfaces. If the "typical collector system" capability is not appropriate, the simulation may be accomplished on a detailed lot-by-lot and block-by-block basis. That detailed simulation is performed by specifying each runoff plane and channel element as a separate subbasin and routing reach.

The capability to represent impervious and pervious areas could be accomplished by artificially separating the subbasin into two more subbasins. The artificial subbasins would be characteristic of pervious and impervious runoff. This would have the same effect for the overland flow segments, but not for the channels. Both types of overland runoff typically flow into the same runoff collector channel (maybe a gutter). Thus, when they are treated together, there is a larger volume of flow in the channel than when each is done separately, and the nonlinear flow characteristics could not be reproduced by doing two separate smaller flow components.

This collector system capability allows for use of either kinematic wave or Muskingum-Cunge channel routing. Two main deficiencies in kinematic wave routing (both channel and overland) have been noted in our experience: lack of attenuation and numerical instability. The Muskingum-Cunge method has been found to apply to a much wider range of flow conditions, and be as good as the full unsteady flow solution much of the time[5]. Muskingum-Cunge routing still has numerical stability problems but they are not as limiting as for kinematic wave.

Flow Diversions

Urban storm runoff often encounters blocked or insufficiently sized channels and/or inlets to channels. Typically runoff from the land surface flows down gutters and ponds at storm drain

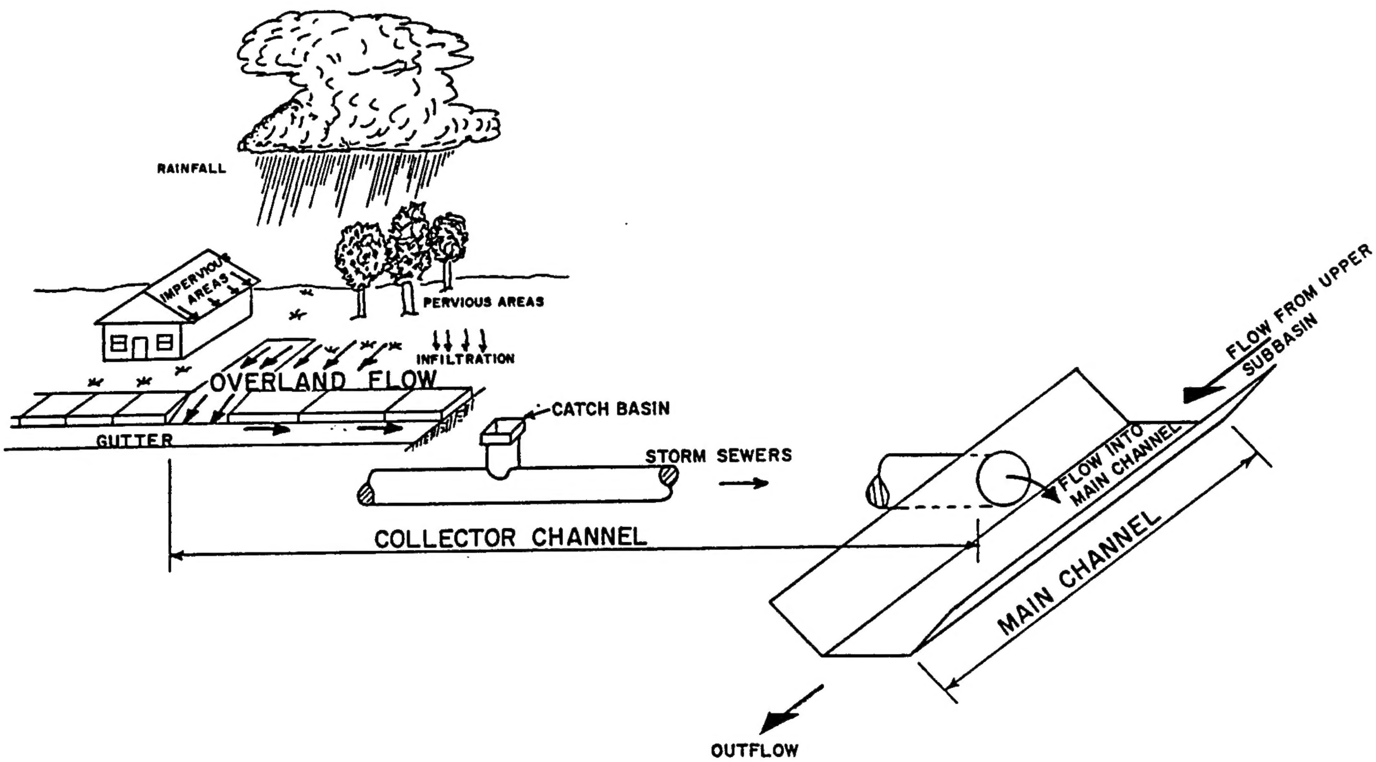

Figure 1. Elements Used in Urban-Runoff Calculations

inlets because the inlet is undersized or the storm drain is already full. Where does the water go? Depending on the terrain, the water may pond at the inlet or flow along the surface streets (channels). To accommodate this situation, HEC-1 has a diversion capability which allows the user to specify the inlet capacity and divert the remaining flow. The amount of the diversion is a function of the incoming flow. The diverted flow is saved and can be retrieved in any subsequent computation; it can be routed through a reservoir to simulate ponding or routed through a separate channel system (e.g., down the streets or in an adjacent channel). Because this flow separation mechanism is so unique to the particular terrain and storm drain characteristics, the diversion and disposition of the diverted flow was not made an automated process in HEC-1.

Flow Constrictions

Another problem in urban areas is insufficiently sized culverts at road crossings. These constrictions turn the open flow channel into a reservoir. The level-pool reservoir routing feature of HEC-1 can handle these conditions very effectively. If the culvert is submerged most of the time, then the orifice outlet capability of the dam routing may be used. If the flow exceeds the roadway, then the road may be represented as a nonlevel top-of-dam. For cases where open channel flow conditions are prevalent in the culvert, then a separately-determined rating curve for the culvert and top of the roadway must be computed and input to the dam routing.

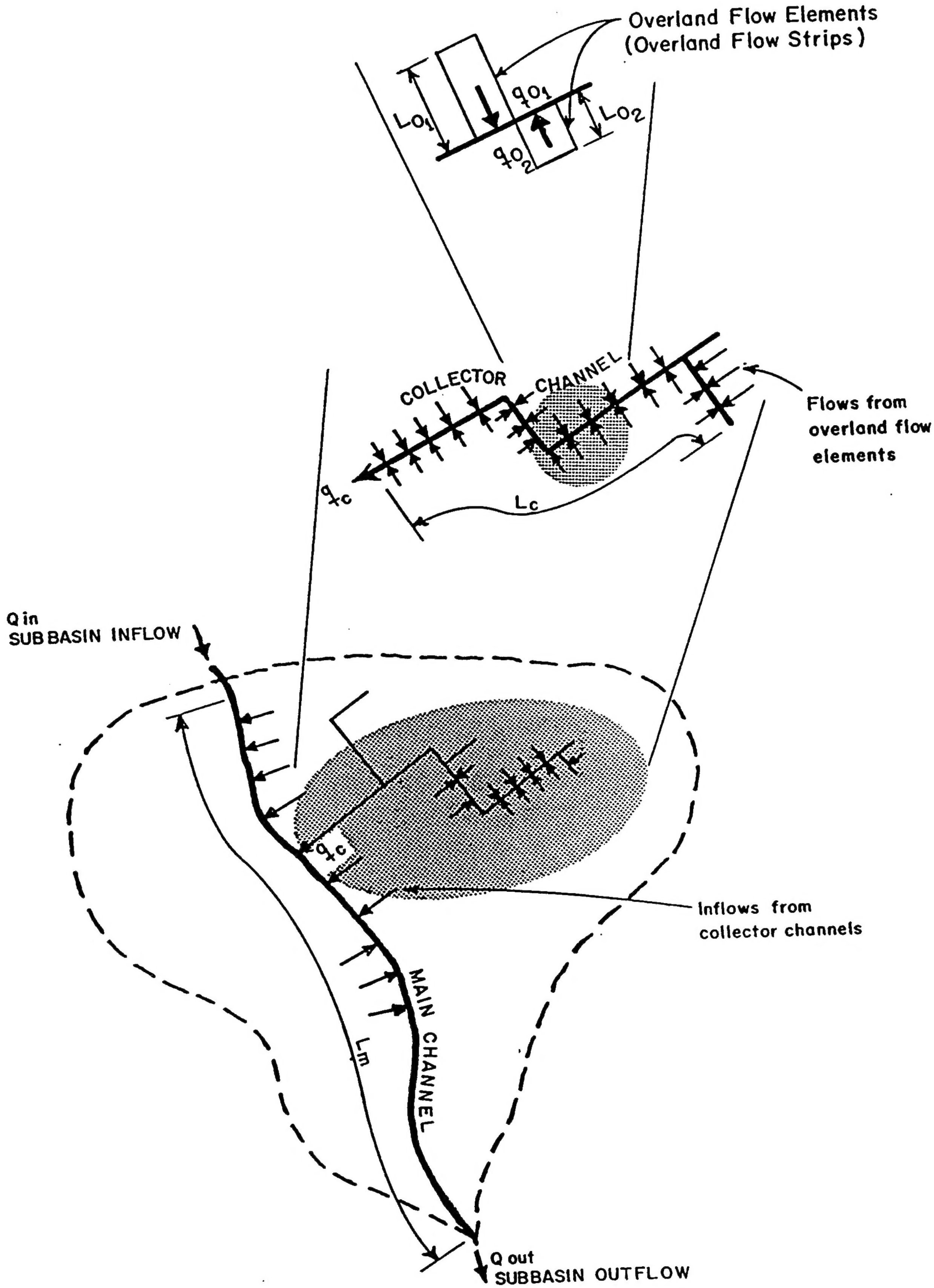

Figure 2. Subbasin Collector System

Pumping

In relatively flat urban areas, pumps are often installed to lift the flow to reduce excessive depth construction costs and to dispose of the water into a river or flood control channel. A pumping capability was added to HEC-1 to lift flood water over levees in interior flooding situations. (A more thorough capability, HEC-IFH, for simulating interior flood situations is presented in a subsequent section of this paper.) Pumping is accomplished as part of a reservoir routing. As the reservoir water surface elevation increases, pumps are turned on at different elevations. There are separate on and off elevations for each of five pumps in HEC-1. The pumped water is handled in the same manner as the flow diversions, i.e. it can be retrieved in any subsequent computation. The water that is not pumped either stays in the reservoir (sump or bay) or flows out a gravity outlet.

Modifying Flow-Frequency Curves

One of the key questions in analyzing a flood damage reduction project is: what is the modified flow-frequency curve with the proposed project in place? The frequency curve together with a flow-damage relationship allows one to compute expected annual damage reduction to analyze the economic efficiency of the proposed project. The multi-ratio and multi-plan capability in HEC-1 performs this modified frequency curve determination. It requires that a flow frequency curve be provided for existing conditions. Then HEC-1 simulates a series of different-sized storms (ratios) for both the existing and alternative future basin conditions to compute the modified frequency curve. The typical application in an urban area is to compute the modified frequency curve for a change in land use (alternative 'plan'). Then, compute the modified frequency curve for a change in land use and the addition of a detention storage reservoir (another 'plan'). This is easily accomplished with the HEC-1 urban runoff and reservoir routing simulation in a multi-ratio, multi-plan format.

Optimizing the Size of Flood Damage Reduction Projects

The size of a flood damage reduction project can be optimized for economic efficiency[6]. This computation combines two major features of HEC-1: expected annual damage computation and the automated parameter estimation algorithm. With the addition of cost-versus-size relationships for the projects in question, HEC-1 searches different project sizes to find which one minimizes the sum of costs and damage. This is equivalent to maximum-net-benefit measure of economic efficiency. Thus, a detention reservoir may be automatically sized for maximum economic efficiency.

HEC-IFH, INTERIOR FLOOD HYDROLOGY

Some flood damage reduction projects, such as levees and flood walls, usually involve special problems associated with isolated interior urban areas. Storm runoff patterns are altered and remedial measures are often required to prevent increased or residual flooding in the interior area due to blockage of the natural flow paths. Hydrologic analyses are needed to characterize the interior area flood hazard and to evaluate the performance of the potential flood damage reduction measures and plans. The HEC-IFH program[7] was conceived to meet this need.

HEC-IFH is a comprehensive, interactive program that is operational on extended memory PC's. It is particularly powerful for performing long, historical-period simulations to

derive annual- or partial-series interior elevation-frequency relationships for various configurations of interior features such as gravity outlets, pumps, and diversions. It makes extensive use of a menu-driven user interface, statistical and graphical data representations, and data summaries. An engineer may use either a continuous simulation or hypothetical event approach depending on the type of study.

Continuous simulation analysis (also called a period-of-record analysis) uses continuous historical precipitation to derive streamflow records, see Fig. 3. HEC-IFH is designed to accommodate complete continuous simulations for at least 50 years of hourly records. However, these are not the absolute limits of the program's capabilities. For example, total periods of up to 100 years and time increments as small as 5 minutes may be used, although significant increases in data storage requirements and computation time will result.

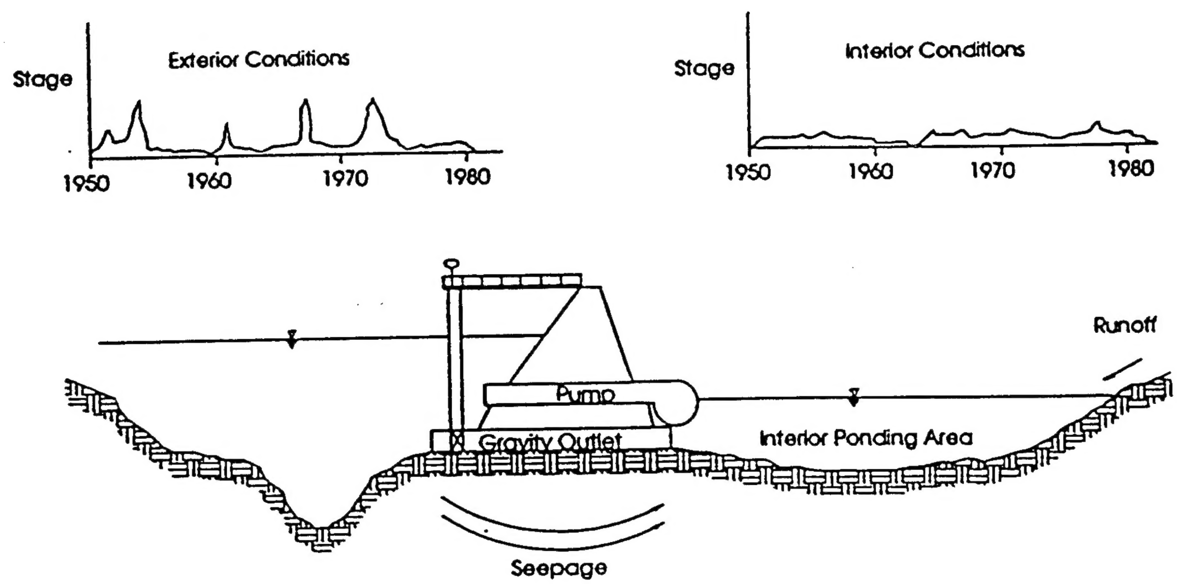

Figure 3. Interior-Flood-Hydrology Continuous Simulation

Hypothetical-event analysis is generally applicable when interior and exterior flood events are dependent. The analysis can be conducted so that the same series of synthetic storm events occur over both the interior and exterior areas. This analysis method can also be applied using a constant exterior stage, or for any "blocked" or "unblocked" gravity outlet condition.

STORM

The original version of the STORM program[8] was completed in January 1973 by Water Resources Engineers, Inc., WRE, of Walnut Creek, California, while under contract with HEC. STORM analyzes the quantity and quality of runoff from urban or nonurban watersheds. The purpose of the analysis is to aid in the sizing of storage and treatment facilities to control the quality and quality of storm water runoff and land surface erosion. The model considers the

interaction of seven storm water elements: rainfall/snowmelt; runoff; dry weather flow; pollutant accumulation and washoff; land surface erosion; treatment rates; and detention reservoir storage. The program is designed for period-of-record analysis using continuous hourly precipitation data.

The quantity of storm water runoff has traditionally been estimated by using a design storm approach. The design storm was often developed from frequency-duration-intensity curves based on rainfall records. This approach neglects the time interval between storms and the capacity of the system to control some types of storms better than others. Infrequent, high intensity storms may be completely contained within treatment plant storage so that no untreated storm water overflows to receiving waters. Alternately, a series of closely spaced storms of moderate intensity may tax the system to the point that excess water must be released untreated. It seems reasonable, therefore, to assume that precipitation cannot be considered without the system, and design storm cannot be defined by itself, but must be defined in the light of the characteristics of storm water facilities. The approach used in this program recognizes not only the properties of storm duration and intensity, but also storm spacing and the storage capacity of the runoff system.

Runoff quantity is computed from hourly precipitation (and air temperature for snow) by one of three methods: the coefficient method; the U.S Soil Conservation Service Curve Number technique; or a combination of the two. Any sized basin may be used; for small basins, the calculation is simply an hourly volume accounting. Runoff quality is computed from the washoff of pollutants that accumulate on the land surface and from dry weather sanitary flow. The amount of pollutants washed into the storm drains and eventually to the treatment facilities for receiving waters is related to several factors including the intensity of rainfall, rate of runoff, the accumulation of pollutants on the watershed and the frequency and efficiency of street sweeping operations.

The resulting runoff is routed to the treatment-storage facilities where runoff less than or equal to the treatment rate is treated and released. Runoff exceeding the capacity of the treatment plant is stored for treatment at a later time. If storage is exceeded, the untreated excess is wasted through overflow directly into the receiving waters The magnitude and frequency of these overflows are often important in a storm water study. STORM provides statistical information on washoff, as well as overflows. The quantity, quality, and number of overflows are functions of hydrologic characteristics, land use, treatment rate, and storage capacity.

When the Corps urban studies program ended in the late 1970's, HEC discontinued development of STORM. It has remained in its original form since then, but some private engineering organizations have converted it to the PC environment. STORM was used extensively by consultants doing waste water management studies for EPA. Currently, there is much renewed interest in STORM for use in EPA's National Pollutant Discharge Elimination System effort.

HEC-DSS, DATA STORAGE SYSTEM

Background and Purpose

HEC-DSS[9] was the outgrowth of a need that emerged in the mid 1970's. During that time most studies were performed in a step-wise fashion, passing data from one analysis program to another in a manual mode. While this was functional, it was not very productive. Programs that used

the same type of data, or were sequentially related, did not use a common data format. Also this required that each program has its own set of graphics routines, or other such functions, to aid in the program's use.

HEC-DSS was developed to manage data storage and retrieval needs for water resource studies. The system enables efficient storage and retrieval of hydrologic and meteorologic time-series data. The HEC-DSS consists of a library of subroutines that can be readily used with virtually any applications programs to enable retrieval and storage of information. At present approximately 20 applications programs have been adapted to interface with DSS.

Approximately 17 DSS utility programs have been developed. A number of these programs are for data entry from such files as the U.S. Geological Survey's WATSTORE data base or from the National Weather Services's precipitation data files. Other utility programs include a powerful graphics program, a general editor, and a program for performing mathematical transformations. Macros, selection screens, and other user interface features combine with DSS products to provide a set of tools whose application is limited only by the ingenuity of the user. HEC-DSS is depicted in Fig. 4.

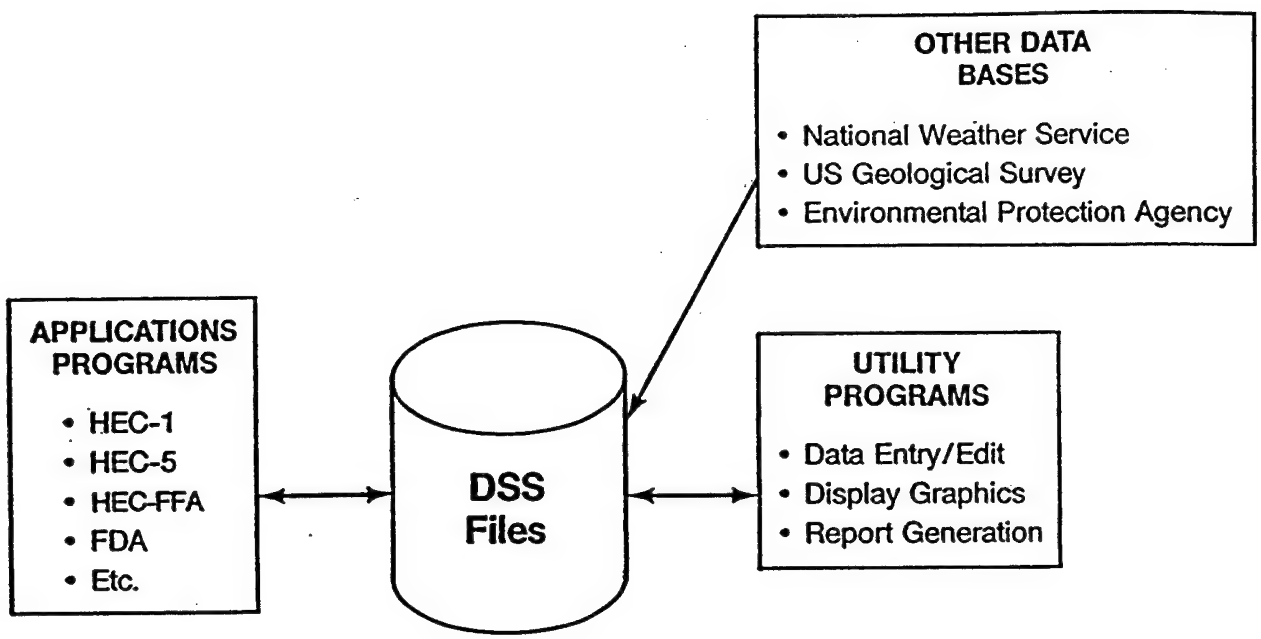

Figure 4. HEC-DSS Data Storage System

Using DSS to Link Several Models

HEC-DSS has played an integral link in several urban modeling studies where more than one model was necessary to solve the problem. In West Columbus, Ohio, the Corps Huntington District used three models to analyze urban flooding: HEC-1, SWMM[10], and HEC-IFH. The land surface runoff was computed with HEC-1 and routed to storm drain inlets. Flow into the inlet was computed and flow in excess of the inlet capacity was stored or routed through another part of the surface system as warranted by the terrain. The extended transport, EXTRAN,

module of SWMM was used to collect the surface inlet flows and route them through the storm sewer system. The surface and subsurface systems drain naturally to several low areas which are now blocked by a levee protecting West Columbus from the main Scioto River. Thus, an interior flooding problem is created at those areas and the runoff must be pumped over the levee. The HEC-IFH model was used to solve the interior flooding problem. HEC-DSS was used to connect the output of one model to the input of the next model. The result was that a complex urban flood problem was disaggregated by detailed simulations of three specialized models whose results were managed by HEC-DSS.

NEXT GENERATION HYDROLOGIC MODELING SYSTEM

In 1990, HEC embarked on a project to develop the next generation, termed NexGen, of its simulation models. The objectives of the new modeling capabilities were to provide the user with better means to visualize and understand the process being simulated, and to build more engineering expertise into the models themselves. The capabilities of modern workstations and PC's using the Windows-NT and UNIX operating systems offer a new level of processing power that could meet these next-generation software needs. Four technical areas are being addressed in the current NexGen effort: river hydraulics, watershed runoff, reservoir system, and flood damage analysis. The new models will have most of the capabilities of the existing HEC models in those areas plus new algorithms where appropriate. The watershed runoff project is called the Hydrologic Modeling System, HEC-HMS.

The intent of this next generation of models is to put the users inside the model and give them the tools to easily work with the data, simulation processes, and results. The user will enter data into a data base that is constructed in a logical engineering-analysis format, not a format for some computer input device. Output will also be stored in the data base for analysis. A graphical user interface will let the user view the data, computations, and results for maximum understanding and analysis of the data and the physical processes.

The ultimate goal is to have smarter models that automatically evaluate numerical stability (time and distance steps) and physical constraints of the process being simulated. The user will be advised of process-simulation problems, and alternative methods and analyses will be recommended where possible. Thus, more engineering expertise will be built into the models to enhance their application and interaction with the user.

New Software Structure

The HEC-HMS model is being developed using "object oriented" technology. Object oriented technology provides a natural way to express a problem, decompose its complexity into understandable entities, and implement program code to solve the problem. Previously most models have been developed by looking at problems from a procedural viewpoint. The procedures that operate on the data were identified, defined, and executed using data supplied when the procedure was invoked. Either the object or the procedural approach can be used to solve a problem. The object perspective coupled with an object oriented computer language can offer some interesting advantages over the procedural approach.

In the HEC-HMS model the hydrologic element objects are the main building blocks. A watershed may be comprised of any number of Subbasins, Reaches, Junctions, or other components. Each hydrologic component object is linked to its associated neighbors to form a dendritic network. Fig. 5 shows an actual network for an area above the Allegheny Reservoir in

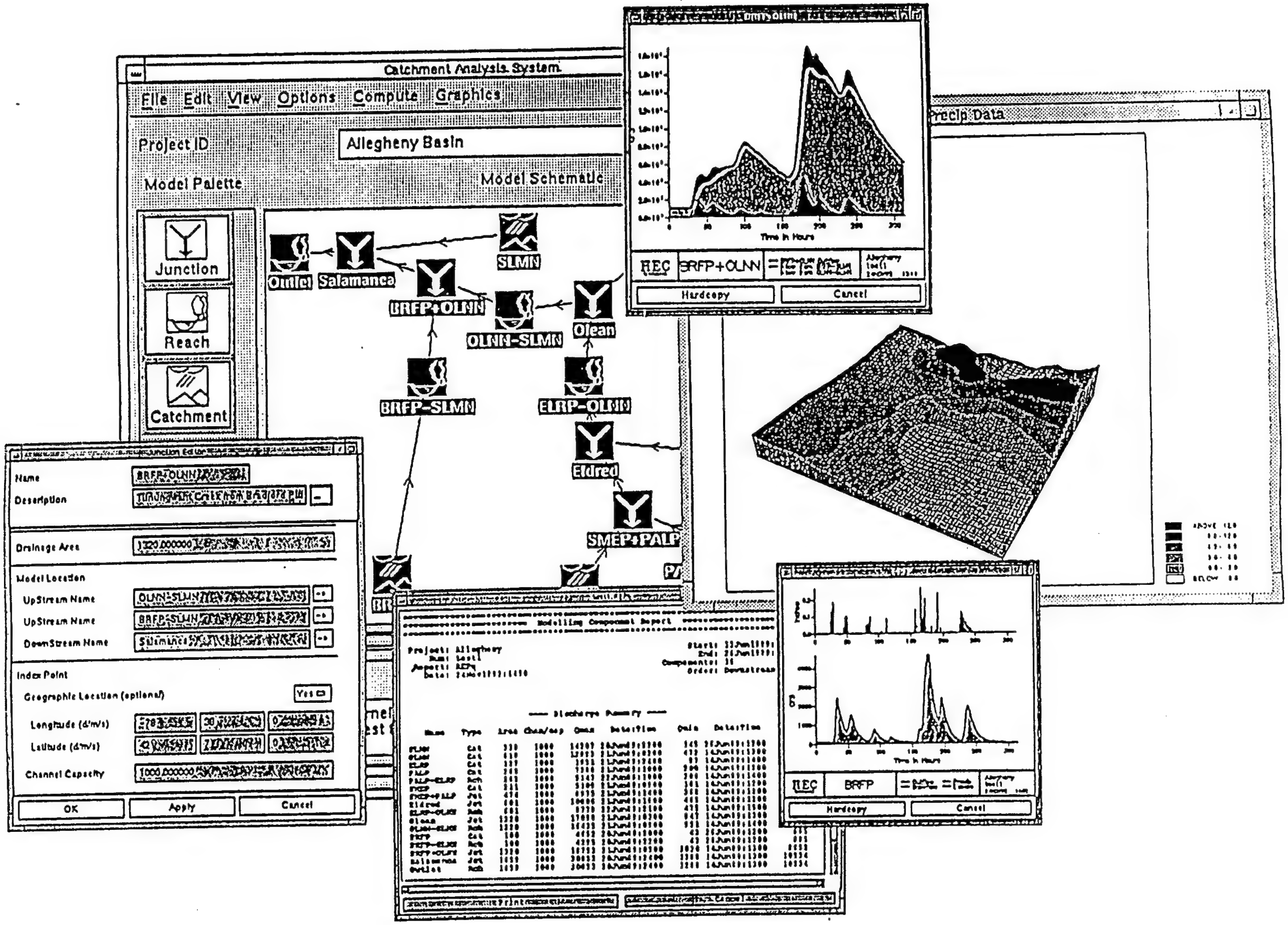

Figure 5. NexGen Hydrologic Modeling System

Pennsylvania. Once the model is configured, some interesting capabilities are possible by using the behavior defined in the component objects.

To compute flows in the system, the outlet is found, and it is requested to compute its flow. The outlet component requests the upstream neighbor for its flow. The compute request works itself up through the object network until components such as Subbasins compute flows from precipitation. As the component flows work their way back downstream, each Reach encountered performs a routing operation, and each Junction combines its inflows. The final result of outflow is then available at the outlet. This illustrates the concept of an object oriented model and the interrelationships that can be defined between objects.

New Algorithms

The initial goal of the project is to field a working model that is useful for accomplishing work similar to that currently done with HEC-1. As such, the model will initially contain the most frequently used algorithms in HEC-1. Later releases will incorporate newer engineering algorithms. The new model framework discussed in the previous section greatly facilitates the expansion of the model to include new technologies. Such new algorithms under consideration include the following.

- Both gaged and spatially distributed precipitation.
- A continuous soil moisture accounting procedure to permit long-period analysis, and improved low-flow simulation and flow forecasting.
- Improved direct runoff response may be possible by use of a transform that accepts a non-uniform excess distribution, where the spatial distribution of precipitation and excess is available.
- Improved baseflow and total runoff simulation.
- Automatic calibration of loss rates to reproduce given flow-frequency curves and given volume-duration frequency curves.

New User Interface

The user interface is the portion of the model that the user "sees" and "touches". In existing models the interface is a text input file, an execution command line, and a text output file. The HEC-HMS makes dramatic changes to the user interface by operating in a window environment with a graphical user interface, GUI. With the GUI the user has the ability to edit, execute, and view model data and results. The watershed configuration is depicted in the main window in schematic form. The schematic in Fig. 5 shows the name and graphic icon for each runoff subbasin, routing reach, and combining junction, along with the linkages that make up the model. The schematic itself may be altered on the screen to add, delete, or change subbasins, reaches, or junctions. Because of the object oriented framework, a newly reconfigured model is able to continue to perform all of its runoff functions without other user actions. The internal object representation used to perform model functions is always consistent with the visual presentation in the GUI schematic.

The GUI is currently the only access to model functionality. While not yet designed and implemented, it has been recognized from the outset that for large project requirements the HEC-HMS model must be able to be driven from other processes, as well as by the interactive GUI user. With the ability to accept commands from other processes, it will be possible to use the HEC-HMS as one component of a larger model encompassing reservoir, river hydraulic,

water quality, and flood damage evaluation models. This will eventually make it possible to investigate a broader range of water resource problems producing an integrated solution across multiple modeling tools.

GIS HYDROLOGY

Some of HEC's earliest work in GIS hydrology involved development of a systematic methodology for automating the data preparation process. The raster-based organization chosen by HEC was called a grid cell data bank. Techniques for use of satellite data, for conversion of polygon data to grid format, and for use of commercially available software to manipulate and convert the data were developed. Parameters for HEC-1 and other hydrologic models were computed by a program called HYDPAR[11] which accessed the grid cell data. In 1975, the grid cell data bank approach was formalized in the HEC Spatial Analysis Methodology, HEC-SAM. Remotely sensed land use and other hydrologic characteristics were also incorporated in the SAM methodology. Later, HEC explored the use of triangular irregular network elements, TINs, for representation of watershed characteristics. A program linking HEC-1 with the TIN was developed in the late 1970's. Because of various hardware, software, and study-management problems associated with the GIS approach, HEC has been less active in the evolution of GIS technology for the past decade.

Recent HEC efforts have included a review of GIS applications in hydrologic modeling[12], and research into a method for combining the spatial GIS data with lineal hydrologic networks. A hybrid grid-network procedure for adapting these existing GIS capabilities for hydrologic modeling is being investigated. Spatially distributed processes are represented on a grid and one-dimensional flow and transport occurs through an associated network. There is a duality between a grid and a network in that once the direction of flow on each grid cell is defined to a single neighboring grid cell, an implied flow network is created. These ideas are being further investigated in HEC's NexGen and remote sensing/GIS projects.

CURRENT R & D ACTIVITIES

In FY 1994, HEC will begin a new urban hydrology and hydraulics R & D work unit. Many more of the Corps flood control investigations are now being conducted in urban areas. Several simulation models exist in the profession to perform these analyses, but each has its particular purpose. Each of the models has limitations too. The intent of this research is to: review the needs of Corps field offices; understand the limitations of existing models; develop guidance for the use of existing models for different types of investigations; and develop new or modified models as necessary to meet the needs. Table 1 summarizes the present status and perceived needs for urban hydrologic modeling capabilities at HEC.

One of the areas of concern is the transition from surface runoff to storm sewer flow. Inadequate inlet capacity and surcharging storm sewers make the simulation difficult. The SWMM EXTRAN module addresses this problem, but has limitations. One consideration will be to use HEC's new unsteady flow routing program, UNET[13], to perform the storm sewer routing. UNET has the capability to simulate flow in looped networks under free-surface and pressure-flow conditions. It presently interacts with HEC-DSS for input and output. UNET will have to be tested in such urban applications in conjunction with HEC-1. A dynamic link between the two models may be desirable.

TABLE 1 HEC Urban Hydrology Capabilities and Needs

Existing	Needed
Hypothetical frequency-based storms:	
Nested intensities balanced in time	Other hypothetical storm distributions
Infiltration:	
Land use-based	Replacement for SCS Curve Number
Lump sum computation	Distribute in time while water is on plane
No recovery during dry periods	Soil moisture accounting
Impervious area	OK
Drainage system:	
Typical collector system or detailed simulation	OK
Two land-surface-runoff planes	OK
No inlet control or check on storm drain capacity	Check for inlet control and storm drain capacity
Collector channel routing	Test diffusion routing in collectors
Channel routing:	
Several hydrologic methods	Additional checks for stability of computation
Kinematic wave and Muskingum-Cunge for typical urban channels	Check for channel capacity and limit flow.
Muskingum-Cunge widely applicable	Test diffusion routing for improvements
No storm sewer hydraulics except via data storage system	More direct connection of HEC-1 to unsteady flow model UNET or SWMM EXTRAN
Diversions:	
Single monotonic function	More flexible function with changes based on time and stage
Pumping stations:	
Fixed computation time interval causes oscillations between "on" and "off" times	Dynamic time interval
Detention storage:	
Level pool reservoir routing	OK
Culvert outflow submerged	Include free surface and pressure flow
Water quality:	
Only STORM computes land surface runoff quality	Add water quality routing or connect through data storage system
Project analysis:	
Fixed channel sizes	Automatic storm drain sizing
Modified flow-frequency curves	Automatic calibration to frequency curve
Flood damage calculation	OK
Multi-flood and multi-project simulation	OK

CONCLUSIONS

Several existing and emerging software packages for urban hydrologic modeling and analysis have been presented. More detailed information on any of the capabilities can be obtained from HEC. The purpose of HEC software is to help solve hydrologic analysis problems faced by Corps field offices. HEC follows a very applications-oriented approach to software development and problem solving. The development of new urban hydrology software will follow this same approach. One of the first tasks in the new R & D work unit will be to host a seminar to bring Corps users in contact with leaders in the urban hydrology profession. It will serve to both apprise the profession of the Corps needs and review the latest capabilities of the profession. With that information in hand, new and modified methods, models, and guidance will be developed. The result will be a set of physically based models with applications guidance for solution of urban hydrology problems in gaged and ungaged areas.

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The Hydrologic Engineering Center, HEC, has several numerical models for simulation of hydrologic and hydraulic processes in urban areas. This paper will focus on new developments and applications procedures for the surface water hydrology models. The primary surface water hydrology model is the HEC-1 Flood Hydrograph Package. It can simulate the precipitation-runoff process in a wide variety of basins, from small urban areas to large river basins. It also has many features which facilitate its application to urban areas. The next generation of HEC-1, termed the NexGen Hydrologic Modeling System, HMS, is currently under development. A new model to analyze flooding in interior areas (e.g. on the land side of a levee) was just released. An older model (STORM) for urban storm water and combined sewer storage and treatment is still used in the profession but not actively supported by HEC. These models (primarily HEC-1) will be discussed in relation to urban hydrologic design. Future directions of the Corps new "Urban Hydrology Methods/Models" research work unit will also be discussed.

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